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Effect of the Herbicide Paraquat on the Decomposition of Wheat Straw

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With 2 figures

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Abstract

The effect 1,1′-dimethyl-4,4′-bipridinium dichloride (paraquat) has on wheat residue decomposition was investigated in laboratory studies. Field dried straw containing 0.30 % nitrogen and 42.9 % C was incubated in laboratory bioreactors for 8 weeks. Treatment combinations per gram of straw were control (no paraquat or spreader), 0.26, 2.6, and 26 ng paraquat, 0.7 nl Valent X-77, 0.26 ng paraquat plus spreader and 2.6 ng paraquat plus spreader. Decomposition was monitored by CO_2 production and dry weight changes. Neither paraquat nor its spreader, alone or in combination, were found to effect CO_2 production or dry weight loss. Paraquat should not increase the rate of wheat straw decomposition at field application rates.

Key words: Crop residue — 1,1′-dimethyl-4,4′-bipyridinium dichloride — Gramoxone — tillage — *Triticum aestivum* — Valent X-77

Introduction

The use of minimum-tillage and no-till in crop rotations depends upon the use of herbicides to control weeks (Teasdale et al. 1991). There is, however, little information on the effect herbicides have on the rate of crop residue decomposition. Reports by local farmers suggest that herbicides such as paraquat may accelerate the breakdown of crop residue (Ohlde 1995). The issue is important because a residue cover protects the soil and conserves water (Skidmore and Siddoway 1978, Unger and McCalla 1981, Smith et al. 1990, Teasdale et al. 1991, Todd et al. 1991).

Paraquat, 1,1′-dimethyl-4,4′-bipyridinium dichloride, is a widely used non-selective herbicide. It is adsorbed strongly by soil particles and in this state is highly resistant to microbial decomposition (Weber et al. 1965, Hance 1967, Knight and Tomlinson 1967, Khan 1973, Lee et al. 1995). Also, paraquat is stable in soil when sorbed by plant residues before being incorporated into the soil (Lee et al. 1995). In clay soils paraquat will move from organic material to soil because of the stronger adsorption properties of clay materials (Knight and Tomlinson 1967, Burns and Audus 1970).

Paraquat is susceptible to microbial degradation while sorbed to plant residues that are on the surface of the soil. There the nitrogen content of the residue may play a role in paraquat degradation with a high C : N ratio in the residue accelerating decomposition. Lee et al. (1995) observed that paraquat degraded faster on rice straw (C : N = 52) than on vetch (C : N = 17), and that added nitrogen slowed the rate of degradation under most conditions. Thus if paraquat has an effect on the degradation of crop residues then it should be strongest with surface residues that have a high C : N ratio.

In this study, the effect paraquat and a spreader (a wetting agent used to improve the application of a herbicide) often used with paraquat has on the decomposition of surface residue was examined. The procedure involved incubations of dried wheat residue, with a C : N ratio of 143, in small laboratory bioreactors under conditions of controlled temperature and moisture. Paraquat treatment levels ranged from the normal field rate to rates that were far higher than would be observed in the field. The higher rates were used to amplify any effect that the normal field rate of application might have on residue decomposition. Residue loss was followed by monitoring dry matter loss while overall microbial activity was monitored by periodic determination of carbon dioxide production.

Materials and Methods

Bioreactors

The residue used in the bioreactors was a field-dried, standing wheat, *Triticum aestivum* cv. Oslo straw. This material had been air dried to a moisture content of 1.2 ± 0.1 % and stored at room temperature. Automated

combustion analysis (Starr et al. 1984) showed that the residue contained 0.30 % nitrogen and 42.9 % carbon. Washed 30 grit silica sand was used as the solid support in the bioreactors. The buffer used (residue buffer) was a pH 6.7 buffer modified from Jawson and Elliott (1986), that contained 0.4 mM $CaCl_2$, 2.9 mM $CaSO_4$, 10μM FeCl, 3.0 mM $MgSO_4$, 1.25 mM NaOH, 20.25 mM NH_4NO_3, 5 mM KH_2PO_4, 50 μM H_3BO_3, 50 μm $MnCl_2$, 2 μM CuCl, 3 μM H_2MoO_4, and 9 μM $ZnSO_4$. The X-77 spreader (Valent Corporation) used was a commercial formulation that contained alkylarylpolyoxyethylene, glycols, fatty acids and isopropanol in proprietary amounts. Paraquat was a commercial formulation, Gramoxone Extra (ICI Americas Inc), that contained 37.05 % of 1,1′-dimethyl-4,4′-bipyridinium dichloride by weight. Bioreactors were 155 ml serum bottles. Each bioreactor contained 1 g of the wheat straw residue (cut into pieces 5–10 mm long), 50 g of sand and 10.8 ml of residue buffer. The straw was placed on the surface of the sand. Paraquat and spreader were incorporated into the buffer solution and the buffer was distributed over the surface of the straw with a pipet. Bioreactors were closed with a foam plug and incubated in the dark at 28 °C.

To assure the presence of a viable population of soil microorganisms a soil-extract-solution was added to the bioreactors. The extract was prepared by suspending 50 g of soil in 50 ml of residue buffer, mixing and centrifuging at 500 × *g* for 5 min. Each bioreactor received 1.2 ml of the supernatant fluid from the soil-extract-solution. The soil was collected at about 10 cm below the surface from a cultivated area.

Studies

Three studies were conducted. Treatments groups of the first were bioreactors without paraquat or spreader (control), bioreactors supplemented with 0.7 nl of Gramoxone Extra containing 0.26 ng paraquat and bioreactors supplemented with 7 nl of Gramoxone Extra containing 2.6 ng paraquat. Treatment groups for the second study were the unsupplemented control bioreactors, bioreactors supplemented with spreader at a rate of 0.7 nl of Valent X-77, bioreactors supplemented with 0.26 ng paraquat plus spreader and bioreactors supplemented with 2.6 ng paraquat plus spreader. Treatments groups for the third study were control (no supplement), 26 ng paraquat (70 nl Gramoxone Extra per bioreactor) and nitrogen (33 μM $NaNO_3$ per bioreactor). The nitrogen treatment supplied the same amount of nitrogen as the 26 ng paraquat treatment. In all treatments the 0.26 ng paraquat and 0.7 nl Valent X-77 rates were estimated to equal a field application rate of 1.75 l ha^{-1} (1 1/2 pints per acre) based on the surface area of the sand in the bioreactors.

The wet weight of each bioreactor bottle was recorded at the start of the study. At weekly intervals the wet weight of each bottle was returned to its initial value by the addition of deionized water.

Measurement of residue loss

At each sampling 8 to 16 vessels from each treatment group were sacrificed for dry weight determinations. These vessels were transferred from the incubator to a 60 °C forced air drying oven. The weight, after drying at 60 °C, of each bioreactor bottle plus contents was recorded at the start of the study, before the addition of the residue buffer. At the end of the study all bottles plus contents were dried and weighed again. The amount of residue loss during the incubation was calculated by subtracting the dry weight of the vessels plus contents from their dry weights at the start of the study. Weights were determined to the nearest mg.

CO_2 determinations

CO_2 measurements, used to monitor microbial respiration, were made using a non-dispersive infrared CO_2 analyser (Easterline Co., Indianapolis). For these determinations bioreactor bottles were equilibrated in a 28 °C water bath for 30 min, closed with a serum stopper, flushed with bottled air (containing 350 μl l^{-1} CO_2) for 5 min, pressurized with a 30 ml injection of bottled air and incubated. At 0 and 30 min samples of the bottles atmosphere were injected through a 2.5 ml sample loop into a line leading to the infrared analyser. Nitrogen gas flowing at 150 ml min^{-1} was used as the carrier gas. Differential measurements were made using a flowing reference cell. This was accomplished by first passing the carrier gas through the reference chamber of the infrared analyser, then to the sample loop and last to the measuring chamber of the analyser. A 2 m coil of tubing (1.65 mm ID) was connected to the outlet vent of the measuring chamber to maintain back pressure and prevent back flow. Peaks were recorded and their areas compared to those of known standards.

Statistical determinations

The Tukey-Kramer multiple comparisons test performed by the Instat computer program (GraphPad Software, Inc.) was used for statistical comparisons. Least significant difference (LSD) determinations were calculated by the method of Fisher as described in LeClerg et al. (1962).

Results

First study

In the initial study the decomposition of wheat straw in the presence of 0, 0.26, and 2.6 ng paraquat were investigated. The effects of these treatments on straw decomposition were monitored over an 8-week period. Both spot or point-in-time CO_2 production and cumulative dry weight change were used to follow the rate of decomposition. In all of the bioreactors the rate of CO_2 production increased rapidly at the start of the incubation reaching a rate of 95–100 μl l^{-1} min^{-1} between week 0.5 and 1 (Fig. 1A). Production gradually declined with time and by week 8 CO_2 production was about 20 μl l^{-1} min^{-1}

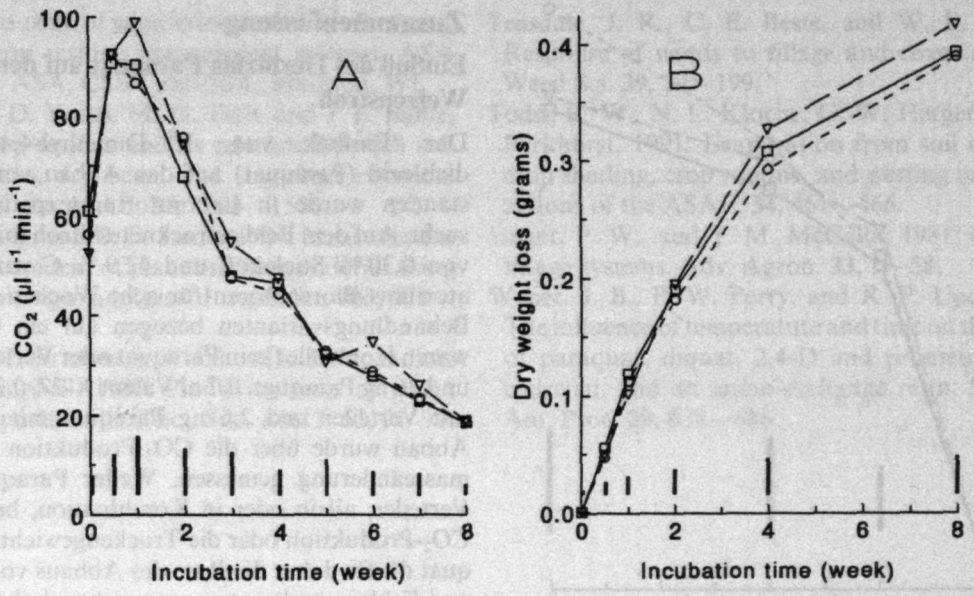

Fig. 1: CO_2 production rates (A) and cumulative dry weight changes (B) of decomposing wheat straw. Treatments were control (—□—), and paraquat at 0.26 ng (–○–) and 2.6 ng (– –▽– –), 1 and 10 times the field application rate respectively. Each point represents the mean of 5–8 independent measurements. Vertical bars indicate LSD (0.05)

in all bioreactors. This pattern was seen with the control bioreactors, that received no paraquat, and in the bioreactors that received supplemental paraquat. The 0.26 and 2.6 ng paraquat treatments had no significant effect on microbial CO_2 production rates. Dry weight changes corresponded well with the CO_2 data. The most rapid change in weight occurred between 0.5 week and 1 week and the rate of weight loss declined gradually with time; by week 8 about 39 % of the weight of the residue was lost from the system (Fig. 1B). Neither the 0.26 nor 2.6 ng paraquat treatments were found to significantly ($P > 0.05$) affect dry weight loss.

Second study

The influence the spreader has on residue decomposition was examined in a second study. Treatments for this study were control, 0.7 nl Valent X-77 spreader (the normal field application rate), 0.7 nl spreader plus 0.26 ng paraquat, and 0.7 nl spreader plus 2.6 ng paraquat. Again, both CO_2 production and cumulative dry weight changes were used to follow microbial activity and residue decomposition. The results (data not presented) with both CO_2 production and dry weight changes were very similar to those of the initial study, and, as before, the treatments had no significant influence on the rate of residue decomposition.

Third study

A slight increase in dry weight loss, that was not statistically significant, was observed at the 2.6 ng treatment level in the first study (Fig. 1B). This numerical increase in dry weight loss suggested that larger amounts of paraquat might have a greater, perhaps significant, influence on residue degradation. This was investigated in a third study. Treatments for this study were a control with no paraquat, paraquat at 26 ng per bioreactor or 100 times the field application rate and a nitrate-nitrogen treatment that supplied the same amount of nitrogen as the 26 ng paraquat treatment. The 26 ng paraquat treatment is an amount that is far higher than would be encountered in the field and was used to magnify any effect that lower concentrations of paraquat might have on the decomposition of residue. Only dry weight loss was monitored in this study (Fig. 2). Cumulative dry matter losses at the end of the 8 week incubation were 0.20 ± 0.05, 0.21 ± 0.06, and 0.25 ± 0.07 g (mean $\pm$ standard deviation), respectively, for the control, nitrogen and 26 ng paraquat treatments. This dry matter loss was less than that observed in the two previous studies. Although the paraquat and nitrogen treatments yielded a numerical increase in dry matter loss, statistical analysis indicated that the treatments did not have a significant ($P > 0.05$) influence on the rate of residue decomposition.

Discussion

During the 8-week laboratory incubation the wheat straw showed considerable decomposition. Colour changed from a light golden tan to a dark brown

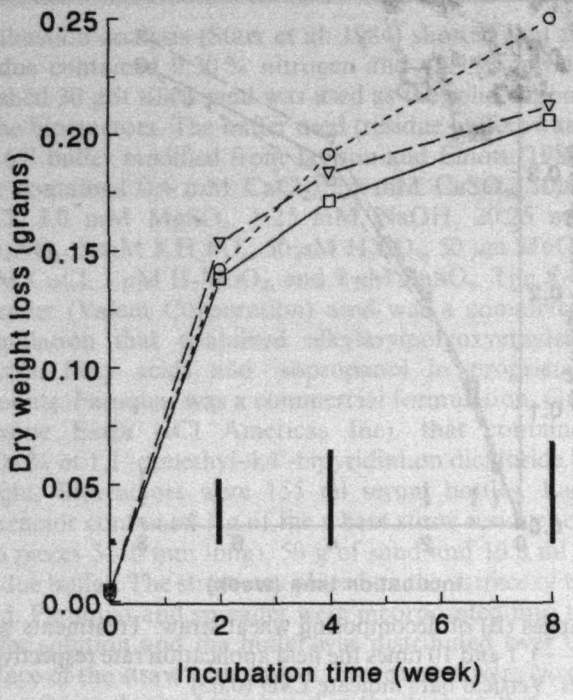

Fig. 2: Cumulative dry weight changes of decomposing wheat straw. Treatments were 26 ng paraquat (–○–), 100 times the field application rate, nitrate-N (– –▽– –) and control —□—). Each point is the mean of 16 independent measurements. Vertical bars indicate LSD (0.05)

and dry weight losses were about 40 % in both the control and treatment groups in the first and second studies and about 20 % in the third study over the 8-week incubation. Under field conditions, where environmental conditions are often less than optimal, residue decomposes at a much slower rate (Stroo et al., 1989). In the field about one-third of the residue may remain after one year (Jenkinson, 1971). In the laboratory, where near optimum conditions of moisture and temperature were maintained, the decomposition that took place during the 8 weeks of incubation was about the same as would be expected to occur in 6–12 months in the field (Daughtry et al., 1996).

Based on these studies the herbicide paraquat had no significant ($P > 0.05$) effect on the rate of residue decomposition under laboratory conditions that approximated 6–12 months of field decomposition and at herbicide application rates that were equal to or far exceeded normal field application rates. The results also suggest that the spreader, Valent X-77, applied at a normal field application rate, should not accelerate the rate of wheat straw residue decomposition.

Zusammenfassung

Einfluß des Herbizids Paraquat auf den Abbau von Weizenstroh

Der Einfluß von 1,1′-Dimethyl-4,4-bipyridiniumdichlorid (Paraquat) auf den Abbau von Weizenrückständen wurde in Laboratoriumsexperimenten untersucht. Auf dem Feld getrocknetes Stroh mit einem Gehalt von 0,30 % Stickstoff und 42,9 % C wurde in Laboratoriums-Bioreaktoren für acht Wochen inkubiert, Die Behandlungsvarianten bezogen auf ein Gramm Stroh waren Kontrolle (kein Paraquat oder Verteiler), 0,26, 2,6, und 26 ng Paraquat, 0,7 nl Valent X-77, 0,26 ng Paraquat mit Verteiler und 2,6 ng Paraquat mit Verteiler. Der Abbau wurde über die CO_2-Produktion und Trockenmasseänderung gemessen. Weder Paraquat noch sein Verteiler, allein oder in Kombination, beeinflußten die CO_2-Produktion oder die Trockengewichtverluste. Paraquat dürfte daher die Rate des Abbaus von Weizenstroh und Feldanwendungsmengen nicht erhöhen.

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